when combined with the appropriate auditory and visual feedback, different 3-D geometries or textures including roughness, smoothness, stickiness, and the like can be effectively simulated.

[0045] Also shown in FIG. **7**C in phantom view are a processor **719** and a memory **721** which are typically utilized to run the software and/or firmware that is used to implement the various features and functions supported by the device **105**. While a single processor **719** is shown in FIG. **7**C, in some implementations multiple processors may be utilized. Memory **721** may comprise volatile memory, non-volatile memory or a combination of the two.

[0046] In POS terminal or kiosk implementations, one or more vibration units configured to provide similar functionality to that provided by vibration unit **712** are fixedly attached to a touch screen that is configured to be movably coupled to the terminal. For example as shown in FIG. **7**D, a touch screen **725** may be movably suspended in a housing **731**, or movably attached to a base portion **735** of the POS terminal **744**. In this way, the touch screen **725** can move to provide tactile feedback to the user while the POS terminal **744** itself remains stationary. The POS terminal **744** generally will also include one or more processors and memory (not shown).

[0047] FIGS. **8**A and **8**B show respective top and side views of an illustrative virtual keycap **808**. Tactile feedback is generated by operation of one or more vibration units (e.g., vibration unit **712** in FIG. **7**) in response to touch so as to impart the perception to a user that the keycap has a depth dimension. In the illustrative example shown in FIGS. **8**A and **8**B, vibration is implemented so that a tactile feedback force profile can be provided using tactile feedback of varying magnitude, duration, and direction, typically by using multiple vibration units. However, in alternative implementations, a single vibration unit may be utilized in order to reduce the parts count and complexity of the device **105** and/or lower costs. In this alternative case, although fewer degrees of freedom of motion are available, a significant perception of 3-D is still typically achievable to a level that may be satisfactory for a particular application.

[0048] As indicated by the dotted-line profile in FIG. **8**B, keycap **808** is provided with a tactile illusion of depth so that it feels as if it is standing off from the surface of the touch screen **110** when it is touched by the user. The user can slide or drag a finger or a stylus across the keycap **808** (as indicated by line **812** in FIG. **8**A), for example from left to right. When the user's touch reaches the edge of the keycap **808**, as indicated by white arrow **815**, a tactile feedback force is applied in a substantially leftward direction, horizontally to the plane of the touch screen **110**, as indicated by the black arrow **818**. (As indicated in the legend **820**, white arrows show the direction of a touch by a finger or stylus, and black arrows show the direction of the resulting tactile feedback force).

[0049] As the user slides from the edge to the virtual top of the keycap **808**, as indicated by arrow **825**, the direction of the tactile feedback force is substantially upward and to the left, as indicated by arrow **830**, to impart the feeling of an edge of the keycap **808** to the user. Providing tactile feedback when the edge of the keycap **808** is touched can advantageously assist the user in locating the keycap in the virtual keyboard simply by touch, in a similar manner as with a real, physically-embodied keyboard.

[0050] As indicated by arrow **836**, when the user touches a central (i.e., non-edge) portion of the keycap **808** with the intent to actuate the keycap, a tactile feedback force is directed substantially upwards, as shown by arrow **842**. In this example, the magnitude of the force used to provide tactile feedback for the keycap actuation may be higher than that used to indicate the edge of the keycap to the user. That is, for example, the force of the vibration from device **105** can be more intense to indicate that the keycap has been actuated, while the force feedback provided to the user in locating the keycap is less. In addition, or alternatively, the duration of the feedback for the keycap actuation may be varied. Thus, it is possible to make the feedback distinctive so that the tactile cues to the user will enable the user to differentiate among functions. As the user glides his or her finger over the keycap, its edges will impact distinctive feedback so that the user can locate the keycap by feel, while a different sensation will typically be experienced when the user pushes on the keycap to actuate it.

[0051] Accordingly, a user will typically locate an object (e.g., button, icon, keycap, etc.) by touch via gliding a finger or stylus across the surface of the touch screen **110** without lifting. Such action can be expected to be intuitive since a similar gliding or "hovering" action is used when a user attempts to locate physically embodied buttons and objects on a device. A distinctive tactile cue is provided to indicate the location of the object on the touch screen **110** to the user. The user may then actuate the object, for example click a button, by switching from hovering to clicking. This may be accomplished is one of several alternative ways. In implementations where a pressure-sensitive touch screen is used, the user will typically apply more pressure to implement the button click. Alternatively, the user may lift his or her finger or stylus from the surface of the touch screen **110**, typically briefly, and then tap the button to click it (for which a distinctive tactile cue may be provided to confirm the button click to the user). The lifting action enables the device **105** to differentiate between hovering and clicking to thereby interpret the user's tap as a button click. In implementations where a pressure-sensitive touch screen is not used, the lift and tap methodology will typically be utilized to differentiate between locating an object by touch and actuation of the object.

[0052] In an alternative arrangement, the force feedback provided to the user can vary according to the "state" of an icon or button. Here, it is recognized that to support a particular user experience or interface, an icon or button may be active, and hence able to be actuated or "clicked" by a user. In other cases, however, the icon or button may be disabled and thus unable to be actuated by the user. In the disabled state, it may be desirable to utilize a lesser magnitude of feedback (or no feedback at all), for example, in order to indicate that a particular button or icon is not "clickable" by the user.

[0053] As the user slides his or her finger further to the right of the keycap **808**, as indicated by arrow **845**, the location of the right edge is indicated to the user with a tactile feedback force that is upwards and to the right. This is shown by arrow **851**. When the user's touch reaches the far edge of the keycap **808**, as indicated by arrow **856**, then a tactile feedback force is applied in a substantially rightward direction, horizontally to the plane of the touch screen **110**, as indicated by arrow **860**. It is noted that a similar tactile feedback force profile can be applied, in most cases, in situations where the user slides a finger or stylus from right to left on the keycap **808**, as well as top to bottom, bottom to top, and from other directions.

[0054] FIG. **9** shows an illustrative application of the present 3-D object simulation using audio, visual, and tactile